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AUTHOR	Haimes, David H.
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ABSTRACT

Analysis of student achievement data following the introduction of graphics calculators to tertiary entrance examinations in mathematics in Western Australia suggests the possibility of an equity problem between the sexes in their usage. While males out-performed females in a number of categories, the most conclusive evidence emerged in questions that were rated as being appropriate for graphics calculator use. (Author)

Science and Mathematics Education Centre

Graphics Calculators in Examinations: A Question of Equity?

David H. Haimes

(HAI99198)

Analysis of student achievement data following the introduction of graphics calculators to tertiary entrance examinations in mathematics in Western Australia suggests the possibility of an equity problem between the sexes in their usage. While males out-performed females in a number of categories, the most conclusive evidence emerged in questions that were rated as being appropriate for graphics calculator use.

Background

For the first time, the use of graphics calculators was allowed in the 1998 Tertiary Entrance Examinations (TEE) in Western Australia. Graphics calculators were allowed in the three mathematics subjects, along with those in the physical sciences. The decision to allow the use of graphics calculators was based on the rationale that, given the technology exists, then why shouldn't its use be allowed, and that developments with scientific calculators had made it difficult to police their use in examinations (personal communication with Curriculum Council officer, November 1999). Some four years' notice was given for their introduction to allow time for schools to make decisions pertaining to curricula and the selection of a suitable calculator. Teachers were therefore afforded an opportunity to familiarise themselves with the uses to which the calculators might be put and to make the necessary adjustments to their teaching procedures and materials.

There are three mathematics subjects examined at the TEE level in Western Australia: Applicable Mathematics, Calculus and Discrete Mathematics. The former two are considered accessible to the top 30% of the age cohort, while Discrete Mathematics is deemed appropriate for the next 30%. Each year, approximately 5000 students sit for Applicable Mathematics, 2000 for Calculus and 6000 for Discrete Mathematics. The smaller numbers who study Calculus reflect its status as a pre-requisite for a limited number of courses at tertiary level.

Theoretical Framework

Graphics calculators are a relatively recent technological development and, for many, continue to be an expensive item to purchase. Together with indecision as to what stage of schooling their introduction is appropriate, it has meant their utilisation as an aid to the teaching of mathematics is yet to become widespread. This is reflected in the somewhat limited scope of the research articles that have been published regarding their effectiveness as a tool for instruction and learning in mathematics. One area in which a significant amount of research has been published is their use in pre-calculus and calculus classes ; Quesada & Maxwell, 1994; .

Another area that has attracted some attention is sex differences associated with the use of graphics calculators. However, studies that have been conducted have produced mixed results. While found that the performance of upper secondary female students who used graphics calculators was clearly superior than that of males on items requiring visual-spatial abilities, found no apparent differences between males and females in achievement regarding spatial visualisation skills related to graphing linear functions. An important difference between Ruthven and Vazquez's studies is that students in the former had used graphics calculators on a regular basis, in the latter study they had not.

In studies conducted with college students, reported that females experienced more difficulties with the introduction of graphics calculators than males. In a subsequent study (1993), they found males were more successful than females on questions that required the integration of graphical and algebraic information, but that overall females significantly out-performed males in the examination. Furthermore, males were found to be disadvantaged in traditional technique based calculus testing. In a more recent study, found that the variable sex did not correlate with Conceptual Mathematical Performance, Basic Algebra Ability, Spatial Visualisation, and Mathematical Confidence, and concluded that this supported the equity of graphics calculator-enhanced instructional practices in college algebra.

As a consequence of their meta-analysis of research on the graphics calculator in mathematics education, concluded that the use of graphics calculators in examinations was an area of research that was particularly under-represented. This, together with the mixed results on sex differences in the use of graphics calculators, suggested a need for further research in these areas. In this study, equity between the sexes in their use of the graphics calculator in examinations was the focus, with the following questions guiding the collection and analysis of data:

Following the introduction of graphics calculators in examinations:

1. *Were there differences in achievement between the sexes when questions were categorised by level of difficulty, nature (procedural or conceptual), or appropriateness for calculator use?*

2. *Were there differences in achievement between the sexes according to the curriculum component?*

Methodology

Data pertaining to student achievement were obtained from the Curriculum Council of Western Australia, the body that administers tertiary entrance examinations. These took the form of students' mean scores for each question (in the case of Applicable Mathematics and Calculus) or part question (Discrete Mathematics) on each of the 1997 and 1998 TEE examinations. The data were further categorised according to the location of the school (country or metropolitan) and by sex (male or female) of the student.

A second set of data was provided by teachers. For each of the three mathematics courses, a panel of five experienced teachers who had taught that course in 1998 were invited to make assessments of the 1997 and 1998 examination papers. With respect to each part question, they were asked to rate its difficulty on a scale of 1 to 5, assess whether it was procedural or conceptual in nature, and indicate whether the use of a graphics calculator would have been appropriate. Inter-rater reliability coefficients were calculated for each mathematics subject and category assessed using the formula

$$r = \frac{(MS_b - MS_w)}{((MS_b - (n-1)MS_w))}$$

where MS_b is Mean squares between; MS_w is Mean squares within and n is the number of cases .

Data obtained from Teacher Panel members were then aggregated. In the case of level of difficulty, the five ratings were summed and each part question was categorised as lower (5 – 11), moderate (12 – 18), and higher (19 – 25) in difficulty. For both nature of question and appropriateness of graphics calculator, a majority vote determined the category. Student mean scores in both Applicable Mathematics and Calculus were provided for whole, not part, questions with the result that, for some, a clear decision was not possible. In these cases, they were categorised as "uncertain." On each of the six examination papers, the marks allocated to questions in the various categories were summed, as were the mean scores obtained by students. From these, proportions of marks actually obtained were calculated.

By using the curriculum outline provided by the Curriculum , the author was able to match examination questions to curriculum component. All but one question from the six papers was matched in this way. The one exception was a question on the 1997 Applicable Mathematics examination with parts from both the Descriptive Statistics and Sets, Counting Techniques and Probability components. This question was not included in the analysis.

Differences in proportions according to sex for both 1997 and 1998 were then tested for significance, using: $p_1 - p_2 \pm 1.96Ö\left[\frac{p_1(1-p_1)}{n_1} + \frac{p_2(1-p_2)}{n_2}\right]$, where p_1 and p_2 are the proportions of successes and n_1 and n_2 the corresponding populations. This expression provides 95% confidence intervals; if the interval does not include zero, the difference in proportions is significant .

Results

Table 1 indicates the numbers of students who sat for each of the mathematics examinations in 1997 and 1998. Most of the student numbers and proportions remained consistent between the two years, the exception being that the proportion of females sitting for the Calculus examination declined further in 1998.

Table 1 – Numbers (%) of candidates for mathematics examinations

	Total	Country	Metro	Male	Female
Applicable '97	4904	804 (16)	4100 (84)	2612 (53)	2292 (47)
Calculus '97	1888	252 (13)	1636 (87)	1270 (67)	618 (33)
Discrete '97	5818	890 (15)	4928 (85)	2301 (40)	3508 (60)
Applicable '98	4976	832 (17)	4144 (83)	2752 (55)	2224 (45)
Calculus '98	1885	253 (13)	1632 (87)	1321 (70)	564 (30)
Discrete '98	5781	890 (15)	4891 (85)	2325 (40)	3456 (60)

Inter-rater reliability coefficients for the teacher assessments are reported in Table 2. They were consistently high, indicating a strong measure of agreement of responses between the five members of each teacher panel.

Table 2: Measurement of Agreement Coefficient for Teacher Rating Scales

	Difficulty of Question	Procedural / Conceptual	Appropriate / Inappropriate
1997 Applicable	.8915	.7627	.7953
1998 Applicable	.9062	.6601	.8976
1997 Calculus	.8120	.6474	.7059
1998 Calculus	.7882	.6877	.7339
1997 Discrete	.7298	.7535	.7180
1998 Discrete	.6822	.7535	.8851

The teacher panel assessments are presented in Table 3. Designated are proportions of the total mark that were allocated to each of the categories as a result of the teachers' assessments. The 'uncertain' category represents questions where a clear-cut decision was not able to be obtained.

Table 3: Teacher Assessment of Examination Items (Percentages)

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	Applicable		Calculus		Discrete	
	1997	1998	1997	1998	1997	1998
Difficulty of Question						
Lower	35	41	20	21	29	13
Moderate	48	36	65	79	71	84
Harder	17	23	15	-	-	3
Nature of Question						
Procedural	35	18	70	60	70	76
Conceptual	43	46	30	26	29	23
Uncertain	22	36	-	16	1	1
Graphics Calculator Usage						
Appropriate	22	23	20	16	17	20
Inappropriate	61	64	75	74	83	78
Uncertain	17	13	5	10	-	2

In Table 4, a breakdown of marks according to the respective curriculum component for each of the three mathematics courses is presented. It is noticeable that, in Calculus, there were some quite different emphases in the 1998 examination when compared with that of 1997.

Table 4: Proportions of Marks According to Curriculum Component (Percentages)

		1997	1998
Applicable	Systems of Equations and Matrices	22	26
	Graphs and Solution of Equations	18	21
	Descriptive Statistics	19	16
	Sets, Counting and Probability	22	22
	Random Variables and their Distribution	19	15
		1997	**1998**
Calculus	Functions and Limits	19	9
	Theory and Techniques of Calculus	14	16
	Application of Calculus	40	46
	Vector Calculus	10	6
	Complex Numbers	17	23
		1997	**1998**
Discrete	Projects, Problem Solving and Investigations	8	8
	Data Analysis	33	33
	Optimisation	24	26
	Growth and Decay	35	33

Differences in proportions by sex according to level of difficulty, nature of question and appropriateness of graphics calculator are found in Tables 5, 6 and 7. The results for level of difficulty indicate there were significant differences in achievement favouring males in the 1998 examinations in Applicable Mathematics (questions classified as moderate in difficulty) and Discrete Mathematics (questions classified as lower and harder in difficulty). Differences in proportions favouring males were significant in questions classified as conceptual in nature only in Discrete Mathematics. However, there were significant differences in proportions favouring males on questions that were considered appropriate for graphics calculator use in each of the three 1998 TEE examinations. No such differences in any of the corresponding categories were significant in 1997.

Table 5: Differences in Proportions by Sex (Male/Female) According to Difficulty of Question

		1997	1998
Applicable	Lower	.743 - .739 (0.029; -0.021)	.760 - .754 (0.030; -0.018)
	Moderate	.579 - .564 (0.042; -0.013)	.524 - .485 (0.067; 0.012) *
	Harder	.519 - .493 (0.055; -0.014)	.406 - .431 (0.002; -0.053)
Calculus	Lower	.789 - .793 (0.035; -0.043)	.694 - .708 (0.031; -0.059)
	Moderate	.718 - .727 (0.034; -0.051)	0.551 - 0.543 (0.057; -0.041)
	Harder	.449 - .396 (0.100; 0.005)*	-
Discrete	Lower	.840 - .829 (0.031; -0.009)	.820 - .739 (0.047; 0.006) *
	Moderate	.668 - .670 (0.023; -0.026)	.627 - .614 (0.039; -0.012)
	Harder	--	.393 - .357 (0.061; 0.010) *

Figures in parenthesis are 95% confidence intervals

* $p < 0.05$

Table 6: Differences in Proportions by Sex (Male/Female) According to Nature of Question

		1997	1998
Applicable	Procedural	.705 - .710 (0.020; -0.031)	.602 - .598 (0.031; -0.023)
	Conceptual	.544 - .548 (0.043; -0.013)	.507 - .508 (0.028; -0.028)
Calculus	Procedural	.739 - .748 (0.033; -0.051)	.684 - .671 (0.059; -0.033)
	Conceptual	.519 - .483 (0.084; -0.012)	.580 - .584 (0.045; -0.052)
Discrete	Procedural	.772 - .778 (0.016; -0.028)	.668 - .656 (0.037; -0.012)
	Conceptual	.597 - .581 (0.042; -0.010)	.557 - .529 (0.054; 0.002) *

Figures in parenthesis are 95% confidence intervals

* $p < 0.05$

Table 7: Differences in Proportions by Sex (Male/Female) According to Appropriateness of Graphics Calculator

		1997	1998
Applicable	Appropriate	.693 - .694 (0.025; -0.027)	.568 - .515 (0.081; 0.025) *
	Inappropriate	.587 - .577 (0.038; -0.017)	.548 - .557 (0.020; -0.036)
Calculus	Appropriate	.745 - .752 (0.035; -0.049)	.643 - .562 (0.130; 0.033)*
	Inappropriate	.659 - .653 (0.051; -0.040)	0.562 - 0.535 (0.076; -0.022)
Discrete	Appropriate	.798 - .801 (0.019; -0.023)	.632 - .605 (0.052; 0.001) *
	Inappropriate	.685 - .683 (0.027; -0.022)	.645 - .632 (0.039; -0.011)

Figures in parenthesis are 95% confidence intervals

* $p < 0.05$

Differences in proportions by sex according to the curriculum component for each of Applicable Mathematics, Calculus and Discrete Mathematics are found in Tables 8, 9 and 10, respectively. In the 1998 examinations, there were significant differences in Applicable Mathematics in both the Graphs and Solution of Equations and Random Variables and their Distributions components favouring males; in Calculus in the Theory and Techniques of Calculus favouring females; and in Discrete Mathematics in the Projects, Problem Solving and Investigations component favouring males. Again, no corresponding differences were significant in the 1997 examinations.

Table 8: Differences in Proportions by Sex (Male/Female) According to Curriculum Component – Applicable Mathematics

	1997	1998
Systems of Equations and Matrices	.711 - .711 (0.025; -0.025)	.629 - .617 (0.039; -0.015)
Graphs and Solution of Equations	.650 - .627 (0.051; -0.003)	.496 - .450 (0.074; 0.018)*
Descriptive Statistics	.621 - .605 (0.034; -0.021)	.747 - .744 (0.027; -0.021)
Sets, Counting and Probability	.590 - .584 (0.035; -0.021)	.489 - .486 (0.032; -0.024)
Random Variables and their Distributions	.501 - .463 (0.066; 0.010)*	.690 - .650 (0.067; 0.014)*

Figures in parenthesis are 95% confidence intervals

* $p < 0.05$

Table 9: Differences in Proportions by Sex (Male/Female) According to Curriculum Component – Calculus

	1997	1998
Functions and Limits	.721 - .713 (0.051; -0.036)	.559 - .561 (0.047; -0.051)
Theory and Techniques of Calculus	.797 - .824 (0.010; -0.064)	.688 - .735 (-0.002; -0.091)*
Application of Calculus	.637 - .657 (0.061; -0.030)	.550 - .525 (0.074; -0.025)
Vector Calculus	.609 - .604 (0.052; -0.042)	.581 - .587 (0.042; -0.055)
Complex Numbers	.607 - .623 (0.030; -0.063)	.551 - .535 (0.066; -0.33)

Figures in parenthesis are 95% confidence intervals

- $p < 0.05$

Table 10: Differences in Proportions by Sex (Male/Female) According to Curriculum Component – Discrete Mathematics

	1997	1998
Projects, Problem Solving and Investigations	.709 - .695 (0.038; -0.010)	.619 - .594 (0.051; 0.000)*
Data Analysis	.749 - .755 (0.017; -0.029)	.621 - .604 (0.042; -0.009)
Optimisation	.727 - .723 (0.029; -0.018)	.704 - .701 (0.027; -0.021)
Growth and Decay	.653 - .651 (0.027; -0.023)	.596 - .575 (0.047; -0.005)

Figures in parenthesis are 95% confidence intervals

* $p < 0.05$

Discussion

A cursory glance at the results could suggest there is strong evidence that allowing the use of graphics calculators in examinations advantages males. However, a more careful examination reveals that such a conclusion may not be altogether warranted.

In examining the data concerning achievement according to the level of difficulty of the examination questions, of those categories in which there was a significant difference in proportions, only that of moderate difficulty questions in Applicable Mathematics warrants further analysis. Marks allocated to these questions constituted 36% of the total for the paper. Furthermore, there was a difference of four percentage points in mean score, favouring males, in the 1998 examination compared with 1.5 in 1997. Significant differences found in the Discrete Mathematics examination are not as convincing, as the lower difficulty questions represented 13% of the total, while higher difficulty were a mere 3% and there was no corresponding category of the latter in 1997. However, with the lower difficulty questions, the difference in mean scores favouring males was 8 percentage points in 1998, compared with one in 1997. While these results are of interest, it is difficult to draw any definitive conclusions as to whether either sex was advantaged according to difficulty of the question.

Data concerning the nature of the question revealed that males performed significantly better than females on questions categorised as conceptual in the Discrete Mathematics examination, these representing 23% of the total marks allocated. The difference in mean scores favouring males was three percentage points in 1998 compared with nearly two in 1997. Again, no definite conclusion can be drawn about achievement according to the nature of the question.

In each of the three mathematics courses, there were significant differences favouring males on questions where the use of a graphics calculator was considered appropriate. The respective proportions of questions in this category for Applicable Mathematics, Calculus and Discrete Mathematics were 23%, 16% and 20%. The differences in mean scores favouring males were 5, 8 and 3 percentage points in 1998 compared with 1, 0.5 and 0 in 1997, respectively. These results suggest that this group of males was more adept than the females at using graphics calculators when answering questions for which their use is considered appropriate. This is in line with Boers and Jones' (1991) findings that females experienced more difficulties than males with the introduction of graphics calculators.

There were four curriculum components in which significant differences in achievement emerged following the introduction of graphics calculators. Three of these favoured males, while one favoured females. The component, Random Variables and their Distributions in Applicable Mathematics, can be discounted since the difference in proportions was also significant in 1997. The difference in mean scores of females and males on the Theory and Techniques of Calculus component, which represented 18% of the total marks, was five percentage points in 1998 compared with two in 1997, each favouring females. This confirms Boers and Jones' (1993) finding that males were disadvantaged in traditional technique based calculus testing.

Significant differences in proportions favouring males were found in the Graphs and Solution of Equations component of Applicable Mathematics (representing 21% of the total marks) and Projects, Problem Solving and Investigations of Discrete Mathematics (representing 8% of the total marks). In the former, the difference in mean scores favouring males was five percentage points in 1998 compared with two in 1997. This lends support to Boers and Jones' (1993) finding that males were more successful than females on questions requiring the integration of graphical and algebraic information. However, little can be read into the result for the Projects, Problem Solving and Investigations component as it represented only 8% of the total marks, while differences in mean scores favouring males increased from one percentage point in 1997 to three in 1998.

The results of this study indicate that there may be a problem with equity between females and males in their use of graphics calculators in examinations. Before any definite conclusions can be drawn, more research into the issue is necessary. If subsequent research confirms the suspicions raised here, then appropriate measures to ensure that females are as comfortable and proficient in their use of graphics calculators will need to be implemented.

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Organization/Address: Science and Mathematics Education Centre Curtin University of Technology GPO Box U1987 PERTH WA 6845 AUSTRALIA	Telephone: +618 9266 4074	FAX: +618 9266 2503
	E-Mail Address: D.Haimes@smec.curtin.edu.au	Date: 19-06-01